Research, Society and Development, v. 9, n. 9, e723997893, 2020
(CC BY 4.0) | ISSN 2525-3409 | DOI: http://dx.doi.org/10.33448/rsd-v9i9.7893

Seeding rates in late sowing affect soybean yield in Southern Brazil

Taxas de semeadura em semeadura tardia afetam a produtividade de soja no sul do Brasil

Las tasas de siembra en la siembra tardía afectan el rendimiento de la soja en el sur de Brasil

Received: 26/08/2020 | Reviewed: 02/09/2020 | Accept: 03/09/2020 | Published: 05/09/2020

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Abstract

Soybean seeding rate (SR) is commonly subject to genotype x environment interactions, and characterization of this interaction is necessary to improve yield potential of future cultivars, especially in late sowing. The objectives of this study were to evaluate yield and yield components of three soybean cultivars in different SR under late sowing in Southern Brazil. We observed an interaction between SR and cultivars under late sowing, in which the increase from 25 to 45 seeds m^{-2} increased yield by 12% and 23% for cultivars BMX Energia and TMG 7262, respectively, while for cultivar AFS 110 there was no SR effect. The cultivars used in this study can be classified from more to less responsive to SR in late sowing as follows: TMG 7262 > BMX Energia > AFS 110. Also, the cultivars used in this study can be classified from higher to lower yield potential in late sowing as follows: TMG 7262 > AFS 110 > BMX Energia. The yield components most correlated to yield were as follows: seeds per area, plant height, 100-seed weight and nodes in main stem, mainly. The increase in SR increased seeds per area and pods per area, while decreased seeds per pod, stem diameter and node number in branches. The identified plant attributes related to yield increase will contribute for developing future cultivars with greater yield potential under late sowing.

Keywords: Cultivar; *Glycine max*; Plant arrangement; Plant density; Productivity; Variety.

Resumo

A taxa de semeadura (SR) da soja está comumente sujeita a interações genótipo x ambiente, sendo necessária a caracterização dessa interação para melhorar o potencial de produtividade de futuras cultivares, especialmente em semeadura tardia. O objetivo deste trabalho foi avaliar a produtividade e os componentes da produtividade de três cultivares de soja em diferentes SR sob semeadura tardia no Sul do Brasil. Observou-se interação entre SR e cultivares sob semeadura tardia, em que o aumento de 25 para 45 sementes m^{-2} aumentou a produtividade em 12% e 23% para as cultivares BMX Energia e TMG 7262, respectivamente, enquanto para a cultivar AFS 110 não houve efeito de SR. As cultivares utilizadas neste estudo podem ser classificadas de maior para menor responsividade a SR na semeadura tardia da seguinte forma: TMG 7262 > BMX Energia > AFS 110. Além disso, as cultivares utilizadas neste estudo podem ser classificadas de maior para menor potencial de produtividade no final semeadura da seguinte forma: TMG 7262 > AFS 110 > BMX Energia. Os componentes do produtividade mais correlacionados com a produtividade foram: sementes por área, altura da planta, peso de 100 sementes e nós no caule principal, principalmente. O aumento da SR aumentou o número de sementes por área e de vagens por área, enquanto diminuiu o número de sementes por vagem, o diâmetro do caule e o número de nós nos ramos. Os atributos identificados com correlação ao aumento da produtividade contribuirão para o desenvolvimento futuras cultivares com maior potencial de produtividade em semeadura tardia.

Palavras-chave: Arranjo de plantas; Cultivares; Densidade de plantas; *Glycine max*; Produtividade; Variedades.

Resumen

La tasa de siembra de soja (SR) está comúnmente sujeta a interacciones genotipo x ambiente, y la caracterización de esta interacción es necesaria para mejorar el potencial de rendimiento de cultivares futuros especialmente em la siembra tardía. Los objetivos de este estudio fueron evaluar el rendimiento y los componentes del rendimiento de tres cultivares de soja en diferentes SR bajo siembra tardía en el sur de Brasil. Observamos una interacción entre SR y cultivares en siembra tardía, en la que el aumento de 25 a 45 semillas m^{-2} incrementó el rendimiento en 12% y 23% para los cultivares BMX Energia y TMG 7262, respectivamente, mientras que para el cultivar AFS 110 no hubo Efecto SR. Los cultivares utilizados en este estudio se pueden clasificar de más a menos sensibles a la SR en la siembra tardía de la siguiente manera: TMG 7262 > BMX Energía > AFS 110. Además, los cultivares utilizados en este estudio pueden clasificarse de mayor a menor potencial de rendimiento a finales sembrar de la siguiente manera: TMG 7262 > AFS 110 > BMX Energia. Los componentes del rendimiento más correlacionados con el rendimiento fueron los siguientes: semillas por área, altura de la planta, peso de 100 semillas y nudos en el tallo principal, principalmente. El aumento de SR aumentó las semillas por área y las vainas por área, mientras que disminuyó las semillas por vaina, el diámetro del tallo y el número de nudos en las ramas. Los atributos de la planta identificados relacionados con el aumento de rendimiento contribuirán a el desarrollo de cultivares futuros con mayor potencial de rendimiento en la siembra tardía.

Palabras clave: Arreglo de plantas; Cultivares; Densidad de plantas; *Glycine max*, Productividad; Variedades.

1. Introduction

Soybean is an important source of oil and protein in agriculture, and its cultivation is spread all over the world. Nowadays it is one of the main crops cultivated in Brazil, with the country ranking among the top producers, producing around 121 million tons of soybean grains in 2019/2020 season, whereas 34 million tons (33%) come from Southern Brazil (CONAB, 2020).

In Southern Brazil, soybean sowing is performed from September to December (early spring to mid-summer). Many growers in subtropical environments delay soybean sowing to late in the season (Spader and Deschamps, 2015; Umburanas et al., 2019) due to the cultivation of winter crops, such as wheat and barley. It's already known that this practice reduces soybean yield potential (Fatichin et al., 2013; Kawasaki et al., 2018; Umburanas et al., 2019), as it reduces canopy size, and shortens the duration of vegetative growth and crop cycle (Pierozan Junior et al., 2017). Some studies suggest that in late sowing, seeding rate management could increase yield (Kawasaki et al., 2018; Umburanas et al. 2019), but this depends on weather conditions.

The study of soybean seeding rates is still an important topic due to the complex phenotypic interactions between genotypes, seeding rates and environments. Each production environment has its particularity and needs a fine tune, for example, there are studies from temperate environments (Ao et al., 2013; Suhre et al., 2014; Agudamu et al., 2016), subtropical environments (Luca et al., 2014; Balbinot Junior et al., 2015; Werner et al., 2016; Umburanas et al., 2019) and tropical environment (Petter et al., 2016).

Soybean cultivars are very sensitive to small changes in environmental conditions, which makes it necessary to evaluate modern cultivars in order to update plant behavior knowledge and seek best management conditions to achieve higher yields (Ao et al., 2013; Spader and Deschamps, 2015).

Increasing seeding rates can speed up inter-row canopy closure (Chen and Wiatrak, 2011; Neugschwandtner et al. 2020), reduce weed biomass (Liebert and Ryan, 2017) and improve the interception of photosynthetically active radiation (Kamara et al. 2014) due to

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plant canopy and morphology adaption (Board and Harville, 1992; Yokoyama et al., 2018). These attributes are related to canopy, which varies greatly among cultivars and environments.

The objectives of this study were to evaluate yield and yield components of soybean cultivars in different seeding rates under late sowing in Southern Brazil.

2. Methodology

a. Site description

The study was carried out in Guarapuava, Parana State, Brazil (25°23' S, 51°29' W; and 1029 m altitude) during the 2014/2015 growing season. The soil of the area (Table 1) is classified as very Clayed Typic Hapludox (USDA, 1999) or *Latossolo Bruno* according to the Brazilian soil classification system (Embrapa, 2018) and surface soil chemical characterization is presented in Table 1.

Table 1. Chemical characterization of the Typic Hapludox at the experimental site in Guarapuava, Parana State, Brazil, 2014.

Depth (m)	P (Mehlich^{-1}) (mg dm^{-3})	O.M. (g dm^{-3})	pH ($CaCl_2$)	Al (cmol$_c$ dm^{-3})	H+Al	Ca	Mg	K	CEC†	SBS (%)‡
0-0.2	1.9	4.4	5.1	0	4.6	2.8	2.3	0.1	9.86	53

O.M. = Organic matter; †Cation exchange capacity; ‡ Soil base saturation. Source: Authors.

Basic fertilization consisted of 22 kg ha^{-1} N, 110 kg ha^{-1} P_2O_5 and 110 kg ha^{-1} K_2O. Soybean seeds were previously treated with fungicides and insecticides. At sowing, seeds were inoculated with a turfy inoculant with *Bradyrhizobium japonicum*, with around 1.2 million viable cells per seed. Pests and diseases were adequately controlled.

b. Experimental design

The experimental design was a randomized complete block in a split-plot with three replications. Main plot size was 35.2 m^2 (11 m × 3.2 m) and subplots 17.6 m^2 (11 m × 1.6 m). Row spacing was 0.4 m and net area of the experimental unit was 9.28 m^2. Two seeding rates

(SR) were used as main plots and three soybean cultivars as subplots. SR were 25 (SR_{25}) and 45 (SR_{45}) plants m^{-2} and cultivars were BMX Energia RR (MG 5.3, indeterminate); TMG 7262 RR (MG 6.2, semi-determined); and AFS 110 RR (indeterminate, MG 5.9).

Sowing was performed on Dec. 20, 2014 in a no-till system and cultural traits were aimed at maximum yield. Plots were over-sown with seeds, and then thinned out at the V_1-V_2 stage (Fehr and Caviness, 1977) to proposed SR's.

c. Evaluations

At R_8 growth stage plants from 7.65 m^2 of the central rows of each plot were harvested and plant mortality rate was evaluated. The following attributes were evaluated: yield; seeds per area; 100-seed weight; pods per area; seeds per pod, and harvest index (HI). The following biometric attributes were also evaluated: plant height, stem diameter, number of nodes in main stem, number of nodes in branches, branches per area, and bottom pod height. HI was calculated by the ratio between seed mass per area to total plant biomass per area in R_8.

d. Meteorological data

Daily rainfall (Figure 1A), temperature (Figure 1B), and solar radiation (Figure 1C) over the experimental period were collected from the Meteorological System of Parana (SIMEPAR) station located 100 m far from experimental area (Figure 1). The Thornthwaite and Mather (1955) sequential water balance was calculated to verify incidence of water deficit during crop growing season (Figure 1A).

Cumulative rainfall was 786.5 mm (Figure 1A), average temperature was 20.4°C (Figure 1B) and accumulated solar radiation was 2105 MJ m^{-2} (Figure 1C) over the season. The ratio of actual evapotranspiration to potential evapotranspiration (ETa - ETp) had a negative balance of 77 mm in the soybean growing season. This shows that rainfall was well distributed, and crop achieved potential evapotranspiration for most of the growing season.

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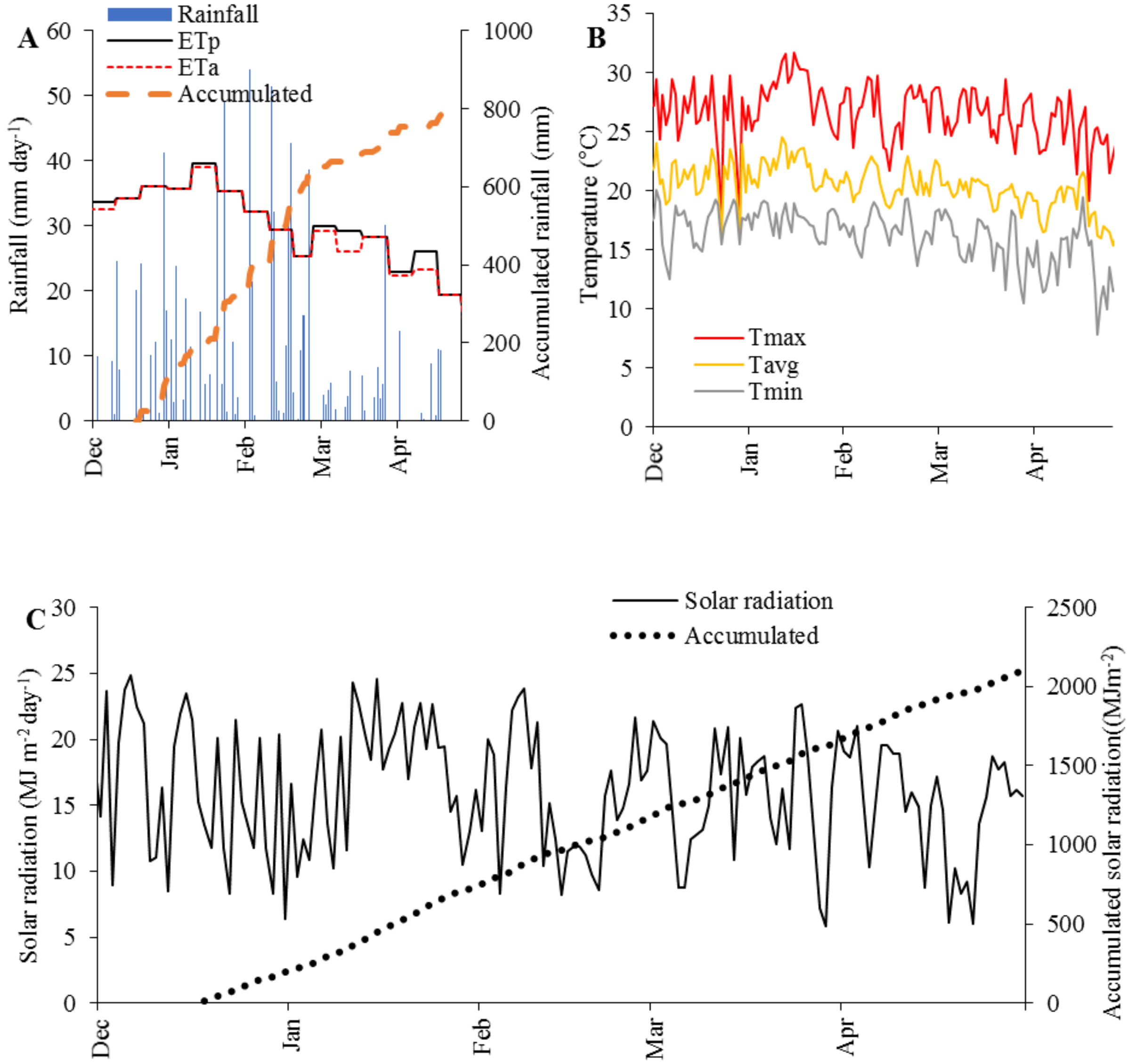
Figure 1. Rainfall (blue bars), accumulated precipitation (gray line), potential evapotranspiration (ETp, red line), actual evapotranspiration (ETa, black line) across growing season (A); daily maximum (red), average (orange), and minimum (light blue) temperatures (B); and daily total solar radiation energy (C) over the soybean 2014/2015 growing season. Guarapuava, Parana state, Brazil.



Source: Authors.

e. Statistical Analysis

The Shapiro-Wilk test was performed and indicated normality for all data. Then, data was subjected to analysis of variance (ANOVA), and when significant ($p \leq 0.05$), least significance difference test (LSD) was performed using Sisvar software (Ferreira, 2019).

The Pearson correlation test was applied between all variables, at $p \leq 0.05$ of

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significance.

3. Results

a. Analysis of variance

For yield attributes there were cultivar and SR interactions on seed yield, seeds per area and seeds per pod (Table 2). Cultivar had significant effect on 100-seed weight and harvest index, whereas SR had significant effect on pod per area (Table 2).

We observed cultivar and SR interaction only on number of nodes in branches (Table 3). Cultivar had significant effect on plant height, nodes in main stem and branches per area (Table 3). SR had significant effect on stem diameter (Table 3).

b. Effects of seeding rate and cultivar on evaluated attributes

The interaction effect in seed yield within cultivar was as follows: for AFS 110 seed yield had no difference between SR_{25} and SR_{45}; for BMX Energia seed yield increased 12% from SR_{25} to SR_{45}; and for TMG 7262 seed yield increased 23% from SR_{25} to SR_{45} (Table 2). The interaction effect in seed yield within SR was as follows: in SR_{25} yield was highest for TMG 7262, intermediary for AFS 110 and lowest for BMX Energia; while in SR_{45} the highest yield was for TMG 7262 and lowest for both AFS 110 and BMX Energia.

The interaction effect in seeds per area within cultivar was as follows: for AFS 110 seed per area had no difference between SR_{25} and SR_{45}; for BMX Energia seed per area increased 13% from SR_{25} to SR_{45}; and for TMG 7262 seed per area increased 23% from SR_{25} to SR_{45} (Table 2). The interaction effect in seed per area within SR was the same for both SR_{25} and SR_{45}: the highest seed per area was for TMG 7262, intermediary for BMX Energia and lower for AFS 110.

Table 2. Yield, 100-seed weight, seed per area, pod per area, seeds per pod, and harvest index of soybean plants in three cultivated varieties and two seeding rates in 2014/2015 growing season at Guarapuava, Parana state, Brazil.

Cultivar (C)	Seeding rate (SR, Plants m^{-2})					
	25	45	Avg.	25	45	Avg.
	Yield (kg ha^{-1})			100-seed weight (g 100 seeds)		
AFS 110	3243 aB*	3242 aB	3242	18.1	18.1	18.1 A
BMX Energia	2884 bC	3241 aB	3063	14.2	14.1	14.1 C
TMG 7262	3983 bA	4883 aA	4433	17.8	17.7	17.7 B
Avg.	3370	3789		16.7 ns	16.6 ns	
	Seeds per area (nº. m^{-2})			Pods per area (nº. m^{-2})		
AFS 110	1787 aC	1795 aC	1791	1193	1459	1326 ns
BMX Energia	2034 bB	2296 aB	2165	1161	1266	1214 ns
TMG 7262	2243 bA	2760 aA	2501	1026	1613	1320 ns
Avg.	2022	2284		1127 B	1446 A	
	Seeds pod^{-1} (nº. pod^{-1})			Harvest index (HI, %)		
AFS 110	1.43 aB	1.24 aB	1.34	0.42	0.42	0.42 A
BMX Energia	1.63 aB	1.79 aA	1.71	0.39	0.31	0.35 B
TMG 7262	2.32 aA	1.65 bA	1.99	0.43	0.42	0.42 A
Avg.	1.79	1.56		0.41 ns	0.38 ns	
MSD	Yield	100-seed weight	Seed nº	Pod nº	Seed pod^{-1}	HI
LSD (C) (0.05)	195	0.25	110	173	0.29	0.06
LSD (SR) (0.05)	159	0.13	86	173	0.20	0.05
C	**0.00**	**0.00**	**0.00**	0.28	**0.00**	**0.05**
SR	**0.00**	0.24	**0.00**	**0.00**	**0.03**	0.22
C ╳ SR	**0.00**	0.99	**0.00**	0.08	**0.01**	0.3
CV_C (%)	4	1	4	11	14	13
CV_{SR} (%)	5	1	4	15	13	14

*Uppercase letters in the column and lowercase letters in the row compare the means by the LSD test at the 5% probability level; ns = non-significant differences at p = 0.05; MSD = Minimum significant difference. Source: Authors.

The interaction effect in number of nodes in branches within cultivar was as follows: for AFS 110, BMX Energia, and TMG 7262 number of nodes in branches decreased 55%, 78% and 31% from SR_{25} to SR_{45}, respectively (Table 3). The interaction effect in number of nodes in branches within SR was as follows: in SR_{25} number of nodes in branches were higher for AFS 110 and lower and equal for BMX Energia and TMG 7262; in SR_{45} number of nodes in branches were higher for AFS 110, lower for BMX Energia, while TMG 7262 did not differ from the others.

Plant height was higher for AFS 110 and TMG 7262, and lower for BMX Energia (Table 3). The number of nodes in main stem follows same trend, and were higher for AFS

110 and TMG 7262, and lower for BMX Energia (Table 3). The branches per area were higher for AFS 110, in comparison to the average of BMX Energia and TMG 7262 (Table 3). Stem diameter and branches per area were higher for SR_{25} in relation to SR_{45} (Table 3). Bottom pod height was not affected by cultivars nor by SR.

Table 3. Plant height, diameter, nodes in main stem, nodes in branches, branches, and harvest index in soybean plants in three cultivated varieties and two seeding rates in 2014/2015 growing season at Guarapuava, Parana state, Brazil.

Cultivar (C)	Plants m^{-2} (SR)					
	25	45	Avg.	25	45	Avg.
	Plant height (cm)			Stem diameter (mm)		
AFS 110	75.4	76.2	75.8 A	7.05	6.09	6.57 ns
BMX Energia	63.1	65.3	64.2 B	7.36	5.96	6.66 ns
TMG 7262	75.9	77.5	76.7 A	6.68	6.21	6.44 ns
Avg.	71.5 ns	73 ns		7.03 a	6.08 b	
	Nodes in main stem per plant (nº $plant^{-1}$)			Nodes in branches - NB (nº $plant^{-1}$)		
AFS 110	17.6	16.8	17.2 A	22.7 aA	10.2 bA	16.5
BMX Energia	15.3	14.2	14.8 B	10.2 aB	2.2 bB	6.2
TMG 7262	17.3	17.4	17.4 A	9.2 aB	6.3 aAB	7.7
Avg.	16.7 ns	16.2 ns		14	6.2	
	Branches per area (nº m^{-2})			Bottom pod height - BPH (cm)		
AFS 110	111	136	123 A	20.9	18.3	19.6 ns
BMX Energia	74	52	63 B	21	21.8	21.4 ns
TMG 7262	54	87	70 B	24	21.9	23 ns
Avg.	79 ns	92 ns		22 ns	20.7 ns	
	Pl. height	Diam.	NMS	NB	Branch.	BPH
LSD (C) (0.05)	5.11	0.54	0.54	3.93	0.87	3.47
LSD (SR) (0.05)	3.4	0.35	0.68	2.83	0.69	2.29
C	**0.00**	0.64	**0.00**	**0.00**	**0.00**	0.14
SR	0.34	**0.00**	0.09	**0.00**	**0.00**	0.24
C × SR	0.94	0.1	0.26	**0.04**	0.15	0.37
CV_C (%)	6	7	3	32	27	13
CV_{SR} (%)	5	6	4	30	29	12

*Uppercase letters in the column and lowercase letters in the row compare the means by the LSD test at the 5% probability level; ns = non-significant differences at p = 0.05; MSD = Minimum significant difference. Source: Authors.

c. Correlation between yield and evaluated attributes

There was a significant positive correlation between yield and the following attributes in decreasing order: seed per area, plant height, 100-seed weight, nodes in main stem, pods per area. We observed no significant correlation between yield and the following attributes:

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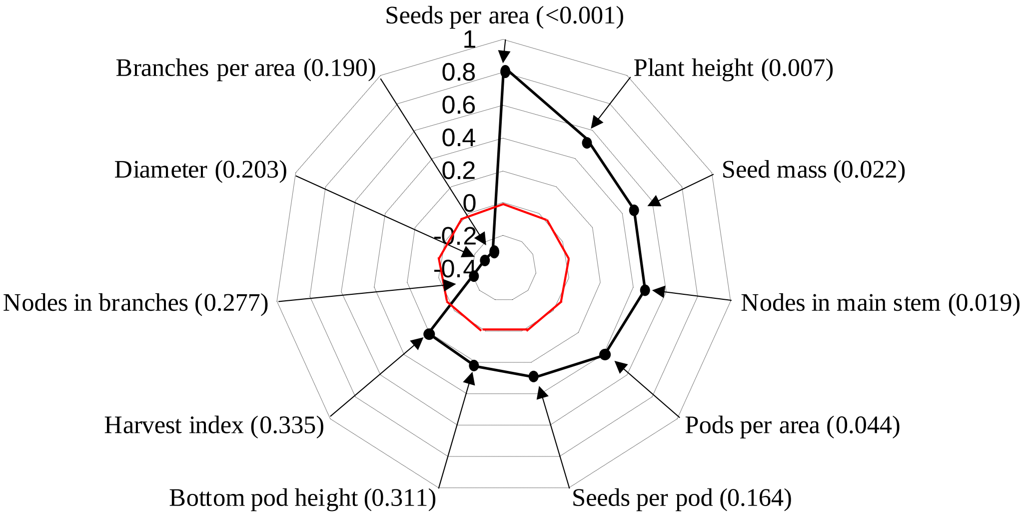
seeds per pod, bottom pod height, harvest index, nodes in branches, stem diameter, and branches per area (Figure 2).

Figure 2. Pearson correlation coefficients between analysed attributes of soybean originated from two seeding rates and three cultivars in the 2014/2015 growing season in Guarapuava, Parana state, Brazil.



Source: Authors.

4. Discussion

Increasing SR from 25 to 45 seeds m^{-2} increased yield by 12 and 23% for cultivars BMX Energia and TMG 7262, respectively, while for cultivar AFS 110 there was no SR effect (Table 2). The greater responsiveness to SR is related to the plasticity of the cultivar, as there is a greater capacity to modify plant canopy to better explore environmental factors.

It is known that the increase in SR can increase yield (Suhre et al., 2014; Spader and Deschamps, 2015), especially in late sowing with the cultivar BMX Energia (Umburanas et al. 2019). Cultivars with susceptibility to lodging should not be used with higher SR (Spader and Deschamps, 2015), being SR management a practice very sensitive to the genotype versus environment interaction.

Late sowing soybeans shortens the crop life cycle and results in less interception of photosynthetically active radiation (PAR) over the growing season than plants cultivated from early sowing date (Purcell et al., 2002). Relatively, late-sown soybeans are submitted to inductive flowering photoperiod earlier than soybeans from earlier sowings, which shortens the period of vegetative growth and total growth cycle length (Pierozan et al., 2015).

Compensatory effect on soybean growth under different plant arrangements, also known as growth plasticity, is widely reported (Cox and Cherney, 2011; Kumagai et al., 2015; Umburanas et al., 2019). The lower yield obtained under SR_{25} in cultivars TMG 7262 and BMX Energia compared to SR_{45} evidences the compensatory effect as a complex trait. In addition, compensatory effect has a limit and it not always results in maximum yield (Table 2). Cultivar AFS 110 showed greater yield stability over evaluated SRs. This is possibly related to a greater equilibrium in PAR interception by the canopy and formation of reproductive organs (drains) over the SR. Results from AFS 110 also evidence that the number of branches per area could be a plant attribute related to yield stability, as this attribute was clearly higher in this cultivar compared to the others in both SR.

Nowadays seed cost represents a low input in soybean production, being feasible for growers to spend more in seeds using higher SRs in late sowing compared to earlier sowing, but it is also necessary to adjust the optimum SR for each production environment. Under average yield potential conditions (~3 Mg ha^{-1}), it was reported that the increase in SR from 16 to 32 seeds m^{-2} provided a small increase in yield, leading to a better cost-benefit ratio using the lower SR (Luca and Hungria, 2014). Higher seeding rate in some cases can also bring disadvantages, such as increased susceptibility to diseases like white mold (*Sclerotinia sclerotiorum*) and soybean rust (*Phakopsora pachyrhizi*), as well as increased wheel damage on plants in field (Cox et al., 2010).

In temperate environments, cultivars with short growth cycle are reported to yield better under late sowing (Salmeron et al., 2014). In the conditions of subtropical environment of Southern Brazil, late-sown soybean still finds favorable development conditions in early autumn, compared to temperate environments, which makes the use of short growth cycle cultivars in these conditions less important. In this study, as an example, a higher yield was found with the cultivar of medium growth cycle (TMG 7262 maturity group 6.2), while lower-yielding cultivars had shorter growth cycle (maturity groups 5.3 and 5.9 for BMX Energia and AFS 110, respectively).

The 100-seed weight within or above recommended SR usually shows no variation (Spader and Deschamps, 2015; Umburanas et al. 2018) as it tends to reach a genetically determined plateau, corroborating our results (Table 3). It was reported that 100-seed weight can reduce in very low SR (Ferreira et al. 2020), probably due to an imbalance on source-sink photoassimilate partition relationship, as in lower SR plants tend to have higher number of pods and seeds per plant.

The seed yield obtained in our study is above national average yield, that is around

3200 kg ha^{-1} (CONAB, 2020), except for BMX Energia under SR_{25}. Adoption of technology already available to farmers can double the present Brazilian soybean yield (Battisti et al., 2018). In our study cultivar TMG 7262 at SR_{45} stands out, yielding 53% (Table 2) more than national average yield.

For seed multiplication, use of lower SR could be favorable, since the ratio of seeds produced by sowed seeds (SR) tends to be higher in lower SR (Umburanas et al., 2019). For the cultivars used in this study, SR_{25} compared to SR_{45} showed seed multiplication rate 40% and 25% higher for cultivars AFS 110 and BMX Energia, respectively. In this study cultivar TMG 7262 showed different pattern, as it had an 8% lower seed yield in SR_{25} compared to SR_{45}. It is important to observe that this cultivar produced a large amount of seeds in both SR.

In this study, AFS 110 showed the highest 100-seed weight, however, had the lowest seed number per area (Table 2), which probably occurred due a smaller drain size (pods and seed number) to source (photoassimilates) availability. In this regard, TMG 7262 stands out, as this cultivar showed a higher 100-seed weight, and the highest seed number per area. This evidences that this cultivar had a larger drain size in the same way it had greater source availability (photoassimilates), probably due to a higher seed filling rate and/or a higher seed filling duration.

Pods per area had no difference among evaluated cultivars, but was 28% higher in the SR_{45} compared to SR_{25} (Table 2), the same trend of higher pod number per area in higher seeding rates within other studies (Suhre et al., 2014; Umburanas et al., 2019).

Seed number per pod is modulated rather by genotype than by environment (Ferreira et al. 2020). Other studies suggest that lower SR can increase the number of seeds per pod compared to higher SR (Ferreira et al., 2016; Ferreira et al., 2020). Within our results, this trend was observed for AFS 110 and TMG 7262, but not for BMX Energia (Table 2), evidencing that this attribute is subjected to genotype versus environment interaction.

The increase in SR can elevate bottom pod height (Umburanas et al., 2019; Neugschwandtner et al., 2020) but this trend was not observed in the conditions of our experiment (Table 3). As late sowing plants usually had lower plant height compared to earlier sowings (Pierozan Junior et al., 2015) this may have contributed to the non-occurrence of this effect, apart from that, this trait varies with cultivar (Neugschwandtner et al., 2020). Howsoever, all treatments in this study had bottom pod height above 15 cm, which is considered suitable for mechanical harvesting.

In our study, the actual evapotranspiration reached the potential evapotranspiration along most of growth cycle, with a low negative balance of -77 mm for the entire period

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(Figure 1A), whereas soil fertility was also in good shape to attend soybean requirements (Table 1). These conditions favored plant to develop and better express the phenotypic potential. In unfavorable environmental conditions, such as severe water stress, or limiting factors that limit yield potential, management of SR will probably not result in yield gain (Kamara et al., 2014; Ribeiro et al., 2017).

The correlation analysis between yield and plant attributes (Figure 2) in different soybean cultivars and seeding rates shows that plants had high adaptability through modulation of yield components. Yield components most related to yield were as follows: seeds per area, plant height, seed mass and nodes in main stem, mainly.

5. Conclusions

We observed an interaction between seeding rate (SR) and cultivars under late sowing, in which the increase from 25 to 45 seeds m^{-2} increased yield by 12% and 23% for cultivars BMX Energia and TMG 7262, respectively, while for cultivar AFS 110 we observed no SR effect. Cultivars used in this study can be classified from more to less responsive to SR in late sowing as follows: TMG 7262 > BMX Energia > AFS 110. Cultivars used in this study can be classified from higher to lower yield potential in late sowing as follows: TMG 7262 > AFS 110 > BMX Energia. Yield components most related to yield were as follows: seeds per area, plant height, seed mass and nodes in main stem, mainly. The increase in seeding rate increased seeds per area and pods per area, while decreased seeds per pod, stem diameter and node number in branches. The identified plant attributes related to yield increase in late sowing will certainly contribute for prospecting future cultivars with greater yield potential under late sowing. The results present yield components and plant attributes related to yield increase in late sowing.

Acknowledgments

We acknowledge funding from Coordination for the Improvement of Higher Education Personnel (CAPES - Brazil) and from National Counsel of Technological and Scientific Development (CNPq - Brazil). We thank the obtentors of the cultivars used in this study for donating the seeds.

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